BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Feasibility of a Lunar Orbital Multispectral Photography Experiment from the CSM - Case 340

DATE: July 17, 1967

FROM: W. L. Piotrowski

ABSTRACT

The feasibility of using instruments and equipment already developed or currently under development for earth orbital experiments is considered for a lunar orbital multispectral photography feasibility experiment. The instrumentation under development is considered in the light of meeting the requirements for a multispectral experiment from the CM in lunar orbit.

Two cases are considered:

1. a nominal Apollo lunar orbital mission in which the available viewing port for the camera assembly is the CM hatch window; and

2. a mission in which the camera viewing port is the Apollo Experiments Airlock window.

In each case the requirements for a camera array are considered and the film/lens filter combinations consistent with the optical qualities of the viewing port are reviewed.

It is concluded that a lunar orbital multispectral experiment is both feasible and desirable using the Apollo Experiments Airlock window and modified instrumentation currently under development for earth orbital experiments. It is strongly recommended that a Hasselblad 500 EL camera body be mated with a UV lens for use in a lunar orbital multispectral experiment and that the 4-unit set of ganged Hasselblad 500 EL cameras be compressed so that the 4 lenses fit inside a 6 1/2 in by 6 1/2 in square. These modifications would have no effect on the usefulness of the instruments for earth orbital studies.

(NASA-CR-87469) FEASIBILITY OF A LUNAR ORBITAL MULTISPECTRAL PHOTOGRAPHY EXPERIMENT FROM THE CSM (Bellcomm, Inc.) 24 p

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MEMORANDUM FOR FILE

INTRODUCTION

Earth-based photography and pictures from Surveyor indicate that different regions of the lunar surface do not exhibit large wavelength-dependent differences in reflection properties in the visible spectral region. This has resulted in relegation of an early, full-scale lunar orbital multispectral photography experiment to a low priority (Ref. 1). However, enhancement of earth-based broad-band multispectral photography has been successful in showing that significant, albeit small, color differences do exist. Many of these variations have been correlated with visible topographic features. Further, on account of atmospheric interference, the earth-based studies have not utilized much of the UV and IR spectral regions where some expected lunar materials (e.g., silicate soils) are expected to show large deviations in reflection as a function of physical and chemical differences.

In view of the above, it is suggested herein that prior to considering a full scale multispectral photographic experiment in lunar orbit a multispectral photography feasibility experiment is a desirable step. Such an experiment is an intermediate step between lunar surface photography from the CM using a single Hasselblad 500C and the proposed Lunar Orbital Multispectral Photography Experiment using multilens cameras, weighing 750 lbs, and occupying 15 ft^3. The experiment would use instrumentation already developed or currently under development for earth orbital studies and would establish the feasibility (including scientific desirability) of lunar surface multispectral photography.

This memorandum considers the feasibility of such an experiment from the CM in lunar orbit and suggests several possible modifications to the instrumentation currently under development. It is assumed that the CM hatch cannot be kept open for the duration of the experiment and, consequently, that CM viewing ports must be used. Two cases will be considered:

Case I: a nominal Apollo lunar orbital mission in which the available viewing ports for the camera assembly are the nominal CM windows, and

[redacted]

Case II: a lunar orbital mission in which the viewing port for the multispectral cameras is the Apollo Scientific Experiments Airlock window.

In each case the requirements for the camera array are considered and a set of film/lens filter combinations consistent with the optical characteristics of the viewing port are reviewed.

If a lunar orbital multispectral feasibility experiment is initiated soon enough, it could have an effect on the sizing of the ganged hand-held cameras being developed for earth orbital experiments and on the selection of a camera for earth orbital UV studies. These instruments would then be appropriate for a lunar orbital multispectral experiment using available photographic viewing ports.

USES OF MULTISPECTRAL PHOTOGRAPHY

Orbital panchromatic photography (e.g., Lunar Orbiter) has few rivals in its ability to define sizes, shapes, relative positions, and extent of objects of interest in vast regions of the lunar surface, but different type objects which exhibit identical grey scale values on panchromatic photographs may be discriminated on multispectral photographs. A comparison of photographs taken in different spectral regions may yield information which simply cannot be obtained by studying the tonal values of a single photograph. The difference may be interpretable in terms of geological and geochemical properties if comparisons can be made with detailed results of similar studies of ground truth data points.

A multispectral photographic experiment is basically a reflection spectroscopy experiment with moderate spectral resolution (~ 500 Å) and extends from the UV to the near IR. The spectral resolution available on each photograph is determined by the film/lens filter combination. A judicious selection of these combinations can result in narrow bands (particularly in the UV using interference filters) or broad bands (in the visible where photography from Lunar Orbiter will be available).

In principle, reflection spectra studies can reveal the gross chemical and, perhaps, the mineralogical nature of the surface and the state of dispersion of the material. In practice, however, it has been found that the surface granularity of a particular solid has a decided influence on the range of reflectivities and, as the material becomes more finely divided, only the broadest spectral features remain. For finely divided materials it becomes exceedingly difficult to employ the reflection spectra obtained from multispectral photography for discrimination purposes. However, the distinction between the spectra of smooth and finely divided material can be used as a distinguishing signature between barren rock and dust covered terrain.

In addition, it is well known that the degree of polarization of the light reflected from the lunar surface is significantly higher for lunar mare than for continental areas. The degree of polarization in the various spectral regions, which may be obtainable from multispectral photography using polarizing filters, is useful in the study of material granulation and possibly gross chemical composition. A unique determination of these properties would not be possible from the polarization curves alone but any interpretation must necessarily be consistent with the polarization data.

MULTISPECTRAL PHOTOGRAPHY FEASIBILITY EXPERIMENT

A lunar orbital multispectral feasibility experiment would have as its objectives:

1) demonstration of the feasibility of multispectral photography for identifying or discriminating lunar surface materials and mapping their distribution, and

2) lunar surface geologic and geographic studies using multispectral synoptic photography.

To accomplish these objectives a multispectral photography feasibility experiment from the CM in lunar orbit would require the following instruments:

1) a set of hand-held cameras mounted together coaxially, mechanically or electrically slaved, and bore-sighted;

2) provision for the crewman to observe approximately the same region being photographed;

3) an events timer to record time and frame number;

4) a suitable viewing port from the CM;

5) a set of film/lens filters to select the spectral band for each camera; and

6) a UV lens for one of the ganged cameras.

All of the above instrumentation either has been developed, is currently under development, or is being studied.

Effectively, the multispectral feasibility experiment suggested for lunar orbit proposes to:

1) use the set of hand-held cameras being developed for earth orbital studies which will be mounted, boresighted, and connected through a wiring harness;

2) replace one of the cameras with an identical camera body mated to a UV lens; and

3) photograph the lunar surface through an appropriate CM viewing port.

Each of these is discussed in turn.

A. Ganged Camera Unit

A 4-unit set of Hasselblad 500 EL 70mm cameras with the 80mm Planar lens and with high capacity magazines (∿ 150 frames/magazine) is currently being developed for the earth orbital Handheld Multiband Terrain Photography Experiment (S065) of Dr. Paul D. Lowman, Jr. (Ref. 2). The cameras are to be mounted together coaxially in a frame, bore-sighted, and electrically slaved through a wiring harness. The unit will be self-contained (using internal batteries) except for connection to an events timer. Provisions are also being studied to provide a viewing capability (i.e., the area being photographed) for the experiment although no final decision has yet been made.

The four cameras are to be mounted such that the lenses will fit inside a 7 in x 7 in square. [This size was selected so that the camera array would have an unobstructed view from the window of the Multiple Docking Adapter (MDA)]. Therefore, if the camera array is mounted normal to a CM viewing port, a 7 in x 7 in internal port is sufficient if the viewing angle is not obstructed. A bracket attachment might be of use in stabilizing the camera unit at the viewing port but this would also require that the area to be photographed be within the camera view angle as determined by the bracket mounting and the spacecraft attitude.

The objective of S065 is to obtain pictures of selected land and ocean areas in four spectral regions simultaneously to gain experience in earth orbital multispectral photography and for geologic, geographic, and oceanographic studies (Ref. 3). To accomplish this objective the principal investigator proposes to use the following spectral bands which are determined by the given film/lens filter combinations (Ref. 4):

1) 5000 - 9000 Å; Color IR Film, Wratten 15 Filter

2) 7000 - 9000 Å; IR Sensitive Film, 89B Filter

3) 6000 - 7000 Å; Plus X Panchromatic, 25A Filter

4) 4800 - 6000 Å; Plus X Panchromatic, 58 Filter

Since this photographic experiment is scheduled to take place from the MDA through an uncoated quartz window, the viewing angle and optical properties of the viewing port are not major problems. For lunar orbital multispectral photography from the CM, however, the size and optical properties of the viewing port are major problems and are discussed in more detail later.

B. UV Photography

Since the moon does not possess an atmosphere which absorbs UV, a multispectral photography feasibility study from lunar orbit should include photography of the lunar surface in the UV since this spectral region is significant in discrimination of soils. At present, there are no Hasselblad 500 EL's with a UV lens which could simply replace one of the cameras in the S065 instrument package. However, MSC is now considering several cameras with UV lenses to perform the UV Airglow Horizon Experiment (S063) since the space-rated Maurer camera with the UV lens has never worked properly. Some of the cameras being considered are:

(1) 35 mm Zeiss with a UV lens;

(2) Hasselblad 500C body with a UV lens;

(3) Hasselblad 500 EL body with a Zeiss UV lens.

Of the three cameras above, the only one acceptable to the present lunar multiband photography study would be the Hasselblad 500 EL body with a Zeiss UV lens. The Zeiss UV lens under consideration at MSC would be f/2, from 50 to 100 mm with a 48° field of view, and have a range of transmission from 2,000 to 7,000 Å (Ref. 2). This camera would easily fit into the array with no modifications to the frame or wiring harness, is capable of taking the high capacity magazines, and would have the same electrical connections as the camera replaced.

The other cameras under consideration for UV photography would require changes in both the mounting frame and wiring harness (the Hasselblad 500C is a mechanically operated camera), thereby negating any advantages in using the array and wiring harness being developed for other experiments. Consequently, for the lunar multiband experiment we strongly recommend the adaptation of a UV lens to the Hasselblad 500 EL body. This same camera would meet the requirements for S063.

C. CM Viewing Ports

Case I: Multispectral Photography Through the CM Windows

To perform a multiband feasibility experiment from the CM in lunar orbit, viewing ports with an unobstructed view and sufficient transmittance in the desired spectral bands are required. The CM contains 5 windows (Ref. 5):

(1) two rendezvous windows;

(2) two side windows; and

(3) a hatch window.

The CM windows are essentially flat - not optically flat but flat enough to take pictures through them with low distortion. Figure 1 shows the location of the various CM windows and Figure 2 shows the approximate shape of each window. Each CM window assembly (Fig. 3) consists of four panels: 1) two inner panels, each 0.20 inches thick with a 0.175 inch spacing between them, installed in the pressure cabin structure; 2) a third panel, 0.70 inches thick, installed in the CM heat shield structure, approximately 1 inch from the inner window assembly and vented to the environment; and 3) an outer panel 0.30 inches thick which is used as a micrometeoroid bumper. The two inner panels are aluminum silicate (Corning Code 1723) with a multilayer antireflective coating (HEA) applied to both sides of each panel. The third panel is amorphous fused silica (Corning Code 7940) UV grade quartz with a magnesium fluoride antireflective coating on the outer surface and a blue-red (UV-IR absorptive-reflective) coating on the inner surface (Ref. 6). The micrometeoroid bumper panel is also constructed of amorphous fused silica (Corning Code 7940) but is not coated (Ref. 5). The CM windows in their spacecraft mounting are stressed and, therefore, photography from the CM using polarizing filters is not feasible (Ref. 5).

The direct spectral transmission through a window assembly (except for the micrometeoroid bumper panel) with all optical coatings is indicated by the solid line in Figure 4. Also shown in the diagram are the transmission and reflection characteristics of the heat shield panel at normal incidence. These spectrographic analyses were conducted under controlled laboratory conditions but it should be pointed out that conducting transmission tests on randomly selected window samples can easily result in a 10 percent variation in transmission. Figure 4 shows that the CM window assembly (except for the micrometeoroid bumper panel) has a transmittance at normal incidence of greater than 75% over the spectral range from about 4300 Å to 7800 Å. The micrometeoroid bumper panel has a transmittance of greater than 90% in the region from 2500 Å to 11,000 Å (Figure 5), making the total transmittance of the four window assembly greater than 65% from 4300 Å to 7800 Å. The optical coatings on the window have a UV cuton at about 4000 Å and an IR cutoff at about 8200 Å. The spectral transmission through the CM window assembly, therefore, is not particularly conducive to a multispectral study in lunar orbit, particularly in the UV and near IR.

The spacecraft window resolution characteristics for the three window assembly of AS-202 are given in Table I. The addition of the micrometeoroid bumper panel is not expected to seriously impair the resolution characteristics of the total window assembly since the panel is Corning fused silica. Therefore, the total CM window assembly will allow a resolution of approximately 40 lines/mm.

A CM window assembly is constructed such that the viewing angle decreases with increasing distance from the inner shell of the CM for each panel of the window assembly (Ref. 5). Therefore, the only CM window with an unobstructed view for the 4-unit camera arrangement being developed for S065 is the hatch window. The CM hatch window is a coated four-window assembly with the following characteristics:

viewing dimensions	∿ 12 in x 14 in
transmittance	> 65%, 4300 Å to 7800 Å
IR cutoff	∿ 8200 Å
UV cuton	∿ 4000 Å
resolution	∿ 40 lines/mm
flatness	visually flat but not optically

Since the hatch window will not allow photography from the CM in the UV and in the near IR and since these spectral bands are particularly important in a multispectral feasibility experiment, a thorough study of the feasibility and desirability of a multispectral photography experiment from the CM in lunar orbit is not deemed possible using the hatch window as a photographic port. Consequently, we recommend that a multispectral feasibility experiment not be performed from the CM through the hatch window.

In the event that a <u>partial</u> multispectral experiment is deemed desirable from the CM using the hatch window, the experiment would necessarily be restricted to the region between about 4,000 Å and 8,000 Å. The film/lens filter combinations and the spectral bands appropriate to each could consist of the following:

1)	4,000 - 4,800 Å	Kodak Spectrum Analysis Plate Film No. 1
2)	4,800 - 6,000 Å	Plus X Panchromatic, 58 Filter
3)	6,000 - 7,000 Å	Plus X Panchromatic, 25A Filter
4)	7,000 - 8,000 Å	IR Sensitive Film, 89B Filter

Case II: CM Airlock Window as a Photographic Port

The nominal CM hatch can be replaced by a hatch which will accommodate the Apollo Scientific Experiments Airlock. A high quality quartz window can be installed on the airlock during flight and can be removed periodically for cleaning. The window is of double panel construction, each panel capable of maintaining pressure integrity, and is fastened to the airlock at the inner door position. Each panel is uncoated amorphous fused silica (Corning Code 7940) 10mm thick and separated by 5/8 in airspace (at positive pressure). Figure 5 details some of the more important optical properties of uncoated amorphous fused silica (Corning Code 7940). From the diagram it can be seen that the airlock window will have a transmittance of greater than 90% in the spectral range from 2500 Å to 11,000 Å, a sufficient range to perform a thorough multispectral feasibility experiment in lunar orbit. Since the space between the panels is pressurized, it necessarily follows that the airlock window in it spacecraft mounting is stressed and therefore that photography using polarizing filters is not feasible.

Figure 6 illustrates the relationship between the outer mold line of the spacecraft, airlock, and window which is such that the overall viewing angle from the center of the window is 49° and 65° across the diagonal. Since the airlock window dimensions are 6 1/2 in by 6 1/2 in, an unobstructed view for the 7 in by 7 in ganged cameras of S065 is not possible. In fact, the view angle for the 80mm Planar lens is 52° and, therefore, an unobstructed view for the ganged cameras is not possible for any position at the airlock window. However, the optical properties of the airlock window are so superior to the CM hatch window for multispectral photography that a slightly occulted view is not considered significantly detrimental to the proposed multispectral feasibility study.

The CM Experiments Airlock window specifications are (Ref. 7):

viewing dimensions	6.5 in square
flatness	within 2 λ of sodium light
transmittance	∿ 90% from 2500 Å to 11,000 Å
UV cuton	∿ 1900 Å
IR cutoff	∿ 24,000 Å
material	fused silica glass (equivalent to Corning 7940)
coatings	none unless requested

A multiband feasibility experiment in lunar orbit using the CM Experiments Airlock window as a viewing port should take advantage of the UV, visible, and near IR portions of the spectrum. The lunar surface photographic experiment using the SWA Hasselblad and S068 color film will demonstrate the desirability of lunar color photography and, therefore, color photography from lunar orbit can be deleted in favor of an additional narrow spectral band, preferably in the near UV.

Multiband photography will be possible in any spectral band between 2500 and 11,000 Å. It is not possible to subdivide the band intelligently into only four appropriate narrow bands for a multispectral feasibility experiment on the basis of our present knowledge. Consequently, we suggest that it would be more suitable to subdivide the band into as many as 12 narrow spectral bands by the inclusion of appropriate film/lens filter combinations. (One film and several interference filters could be used to subdivide the 2500 - 4500 Å band.) It would then be possible to photograph the lunar surface in these 12 bands (using only 4 bands simultaneously) to determine which spectral bands are most suitable for identification and discrimination of lunar surface materials.

RECOMMENDATIONS

To perform a multispectral feasibility experiment from the CSM in lunar orbit the following recommendations are made:

1) The CM airlock window should be used as the photographic viewing port for a lunar orbital multispectral study. An antireflective coating on the four surfaces of the double panel window would be advisable since it would cut down considerably on the surface reflections.

2) The 4-unit set of Hasselblad 500 EL 70 mm cameras being developed for earth orbital use should be mounted closer together so that the lenses would fit inside a 6 1/2 in square. This would permit a less obstructed view through the CM airlock window which in turn permits photography over a wider spectral band than is possible with the CM hatch window. If this recommendation is initiated early in the S065 development program, there should be no major problem in mounting the cameras somewhat closer together (currently there seems to be ∿1/2 in play in the mountings).

3) A Hasselblad 500 EL body should be mated with a UV lens so that photography of the lunar surface in this spectral region would be possible. This would permit the replacement of a camera in the S065 frame with no modification to the frame or electrical circuitry. Since a camera with a UV lens must be developed for the UV Airglow Horizon Experiment (S063), it would be more economical to develop a camera which could be used with both experiments; the Hasselblad 500 EL body mated with a UV lens would meet the requirements of S063.

4) A mounting bracket for the camera unit should be attached to the inner wall of the CM to assist in stabilizing the camera unit at the viewing port. This will require that the CM RCS be used to position the cameras for photography.

5) If the CM hatch window is used as the photographic viewing port for a partial multispectral experiment, a jettisonable cover for the window should be employed on the early phases of the mission. Early Apollo flights have experienced window contamination problems (Fig. 7) due possibly to impinging gases from the jettisoning launch escape tower, etc. Since an ablative plug in the heat shield will protect the CM Experiments Airlock window, no covering will be needed when this window is used as the viewing port.

CONCLUSIONS

A multispectral photography feasibility experiment from the CSM in lunar orbit is a desirable step in the orderly development of a lunar orbital remote sensing program. Such an experiment is feasible on an early lunar orbital flight using the CM airlock window as a photographic viewing port and using instrumentation currently under development for earth orbital studies. At the time procurement of cameras would be necessary for a lunar orbital mission, the Hasselblad 500 EL camera would be an off-the-shelf flight item (Ref. 2). A comprehensive lunar orbital multispectral study will require a camera capable of photography in the near UV and, therefore, it is recommended that a Hasselblad 500 EL body be mated with a UV lens. This camera would also meet the requirements for several UV experiments in earth orbit (e.g., S063).

A lunar orbital multispectral experiment using the CM hatch window as a photographic viewing port would be restricted in the available spectral bands and,therefore,would be a degraded experiment as compared to an experiment using the CM airlock window. However, a partial multispectral experiment using the CM hatch window would be a desirable step above the single Hasselblad 500 C photography planned for the CM on AS-504.

W. L. Piotrowski

1012-WLP-ecz W. L. Piotrowski

Attachments:
Table I
Figures 1 - 7
References

TABLE I - SPACECRAFT WINDOW RESOLUTION CHARACTERISTICS FOR MISSION AS-202

Conditions	Resolution of each window in lines per mm			
	Left rendezvous	Right rendezvous	Left side	Right side
Preflight	40	40	50	50
Postflight, shipboard	20	28	40	5
Postflight, Downey	28	34	40	40

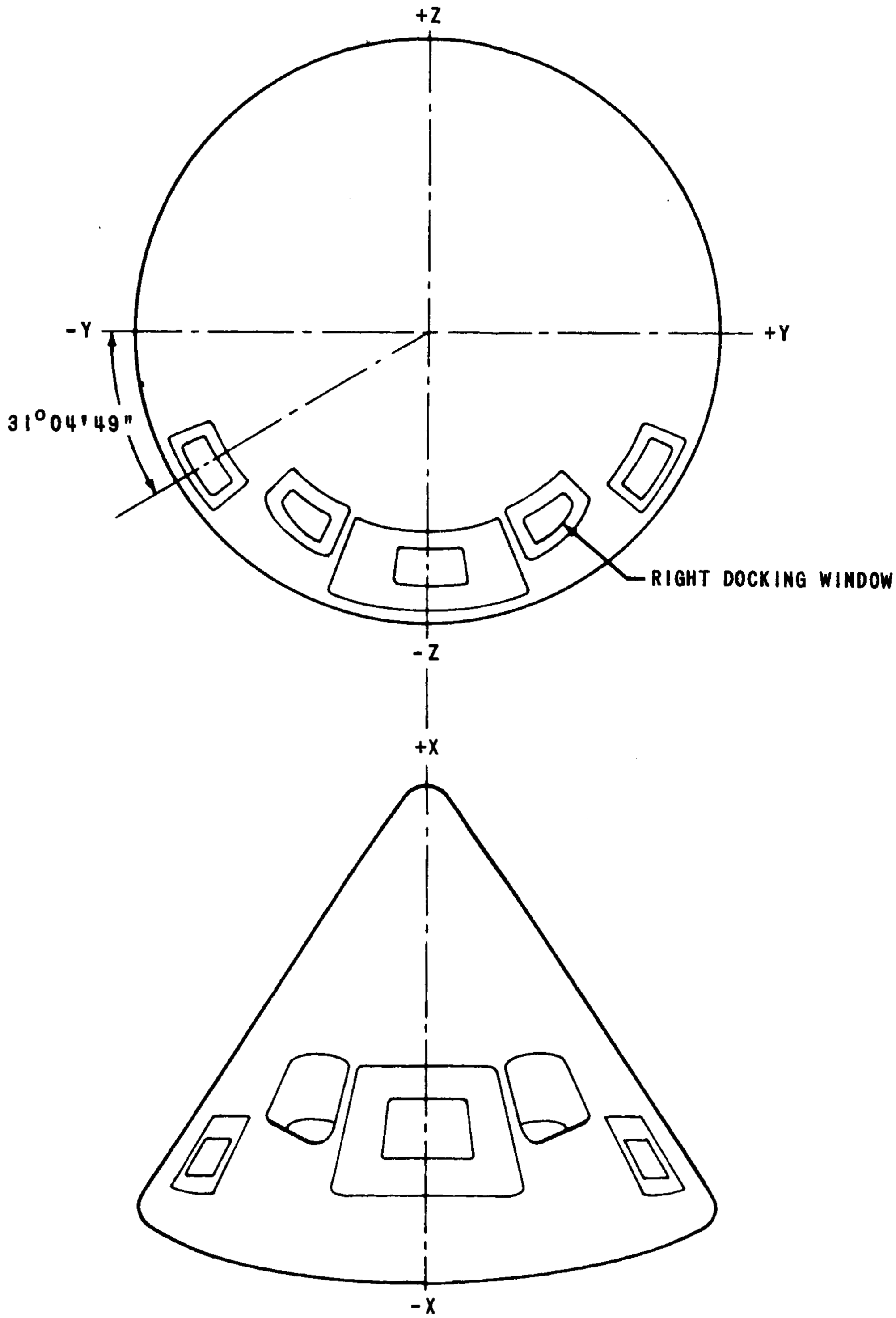

FIGURE 1 - LOCATION OF CM WINDOWS (REF. 6)

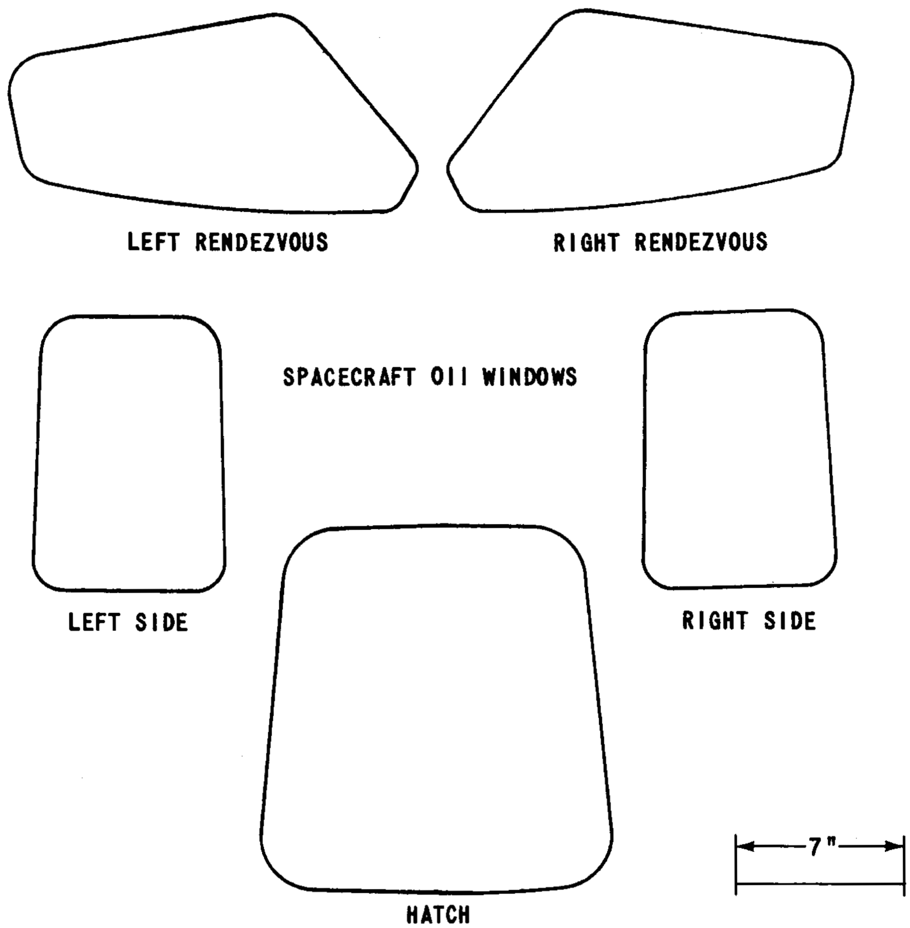

FIGURE 2 - CM WINDOW SIZES AND SHAPES (REF. 6)

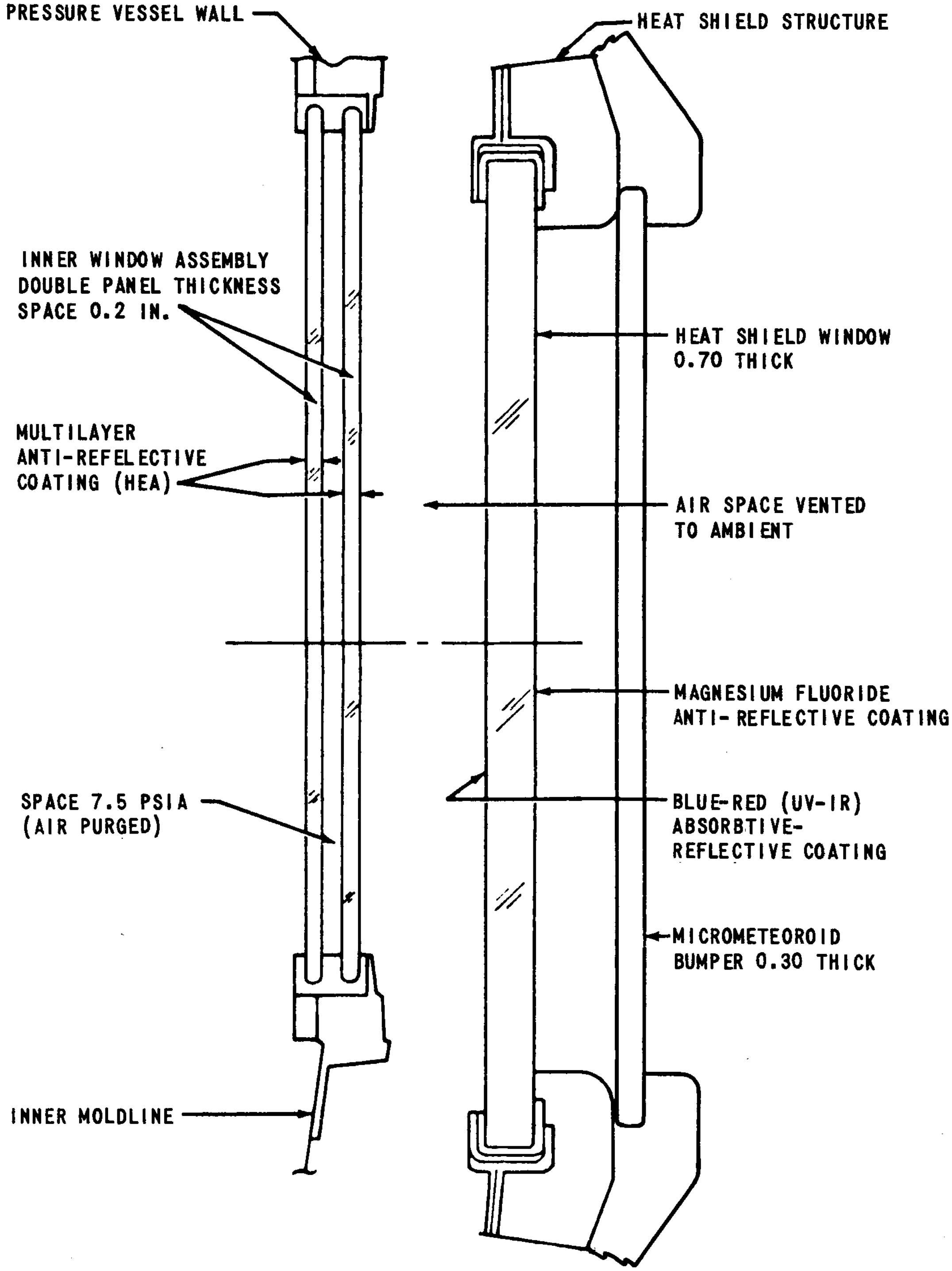

FIGURE 3 - CUTAWAY SHOWING CM WINDOW ASSEMBLY

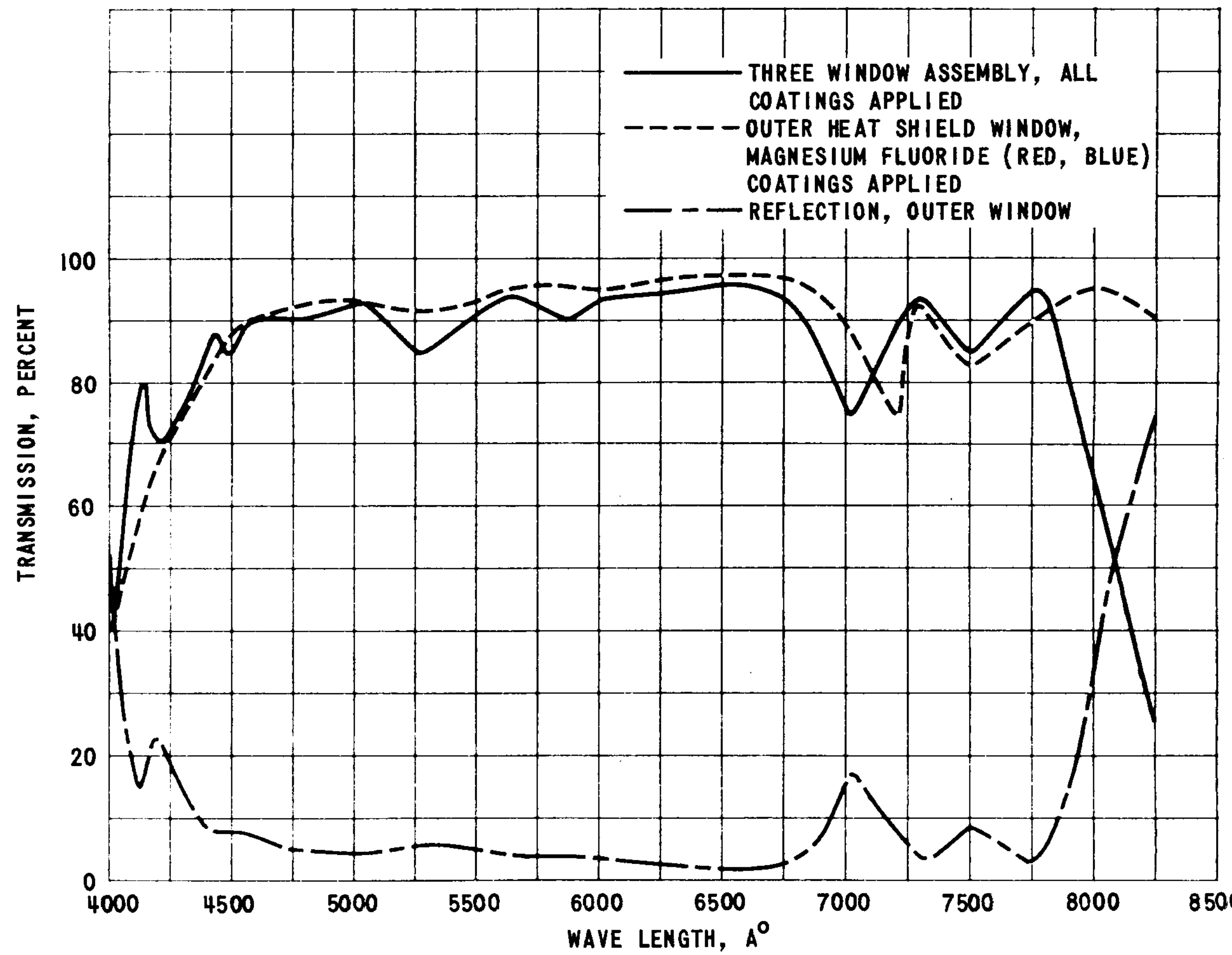

FIGURE 4 - PREFLIGHT SPECTRAL TRANSMISSION CHARACTERISTICS OF CM WINDOWS, MISSION AS-202 (REF. 6)

OPTICAL PROPERTIES

Refractive Index and Dispersion—Typical Room Temperature Values:

n_F (486mμ) 1.46313 n_D (589mμ) 1.45841 n_C (656mμ) 1.45637 $V = \frac{n_D - 1}{n_F - n_C} = 67.8$

Refractive Index Change With Temperature – n_e from 0 to 700°C: $+1.38 \times 10^{-5}$ per °C

Source: L. Prod'homme, Verres et Refractaires 10:267(1956)

Birefringence Constant: 3.40 m mu/cm/kg/cm^2

REFRACTIVE INDEX
Measured at 20°C

Wave Length (Microns)	Index	Wave Length (Microns)	Index
0.213856	1.53428	0.589262	1.45841
0.214438	1.53371	0.656272	1.45637
0.230209	1.52005	0.706519	1.45516
0.239938	1.51337	0.852111	1.45247
0.269885	1.49805	1.01398	1.45025
0.280347	1.49404	1.12866	1.44888
0.296728	1.48873	1.39506	1.44584
0.330259	1.48054	1.52952	1.44428
0.340365	1.47859	1.6932	1.44227
0.346620	1.47745	1.97009	1.43853
0.365015	1.47453	2.1526	1.43575
0.435835	1.46670	2.4374	1.43093
0.486133	1.46313	3.2668	1.41253
0.546074	1.46008	3.5070	1.40565
0.576959	1.45885	3.7067	1.39937

TRANSMITTANCE OF FUSED SILICA CODE 7940
10 mm Thickness — Surface Reflections Included

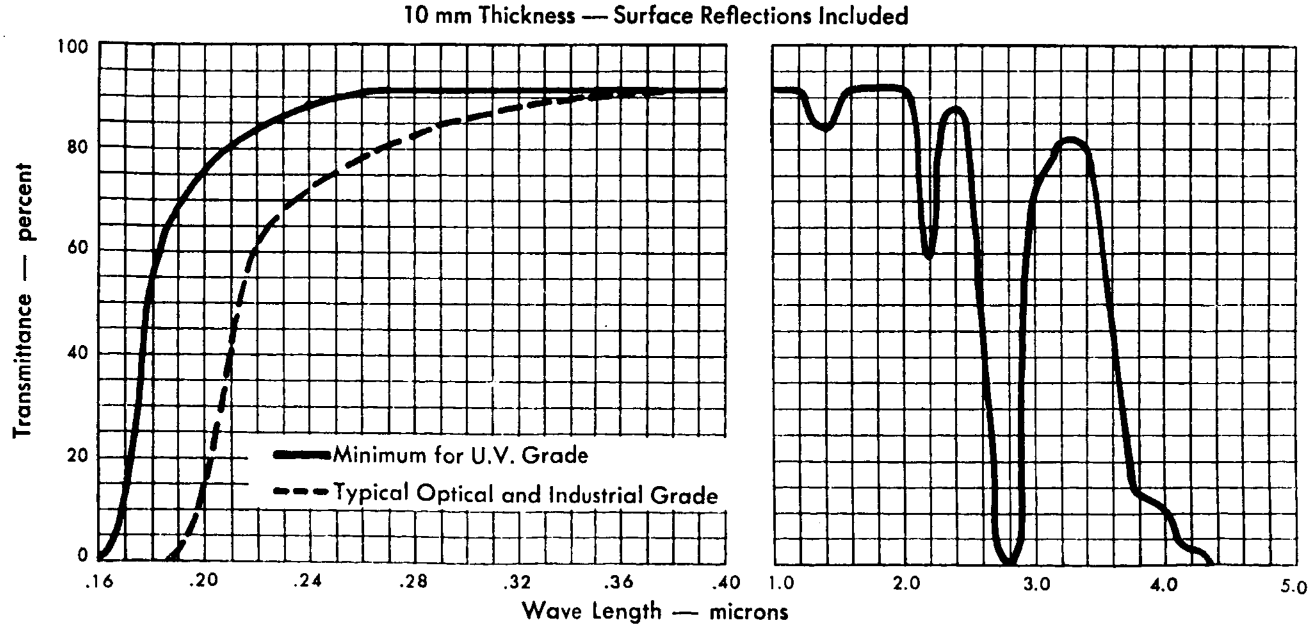

FIGURE 5 - OPTICAL PROPERTIES OF FUSED SILICA (7940)

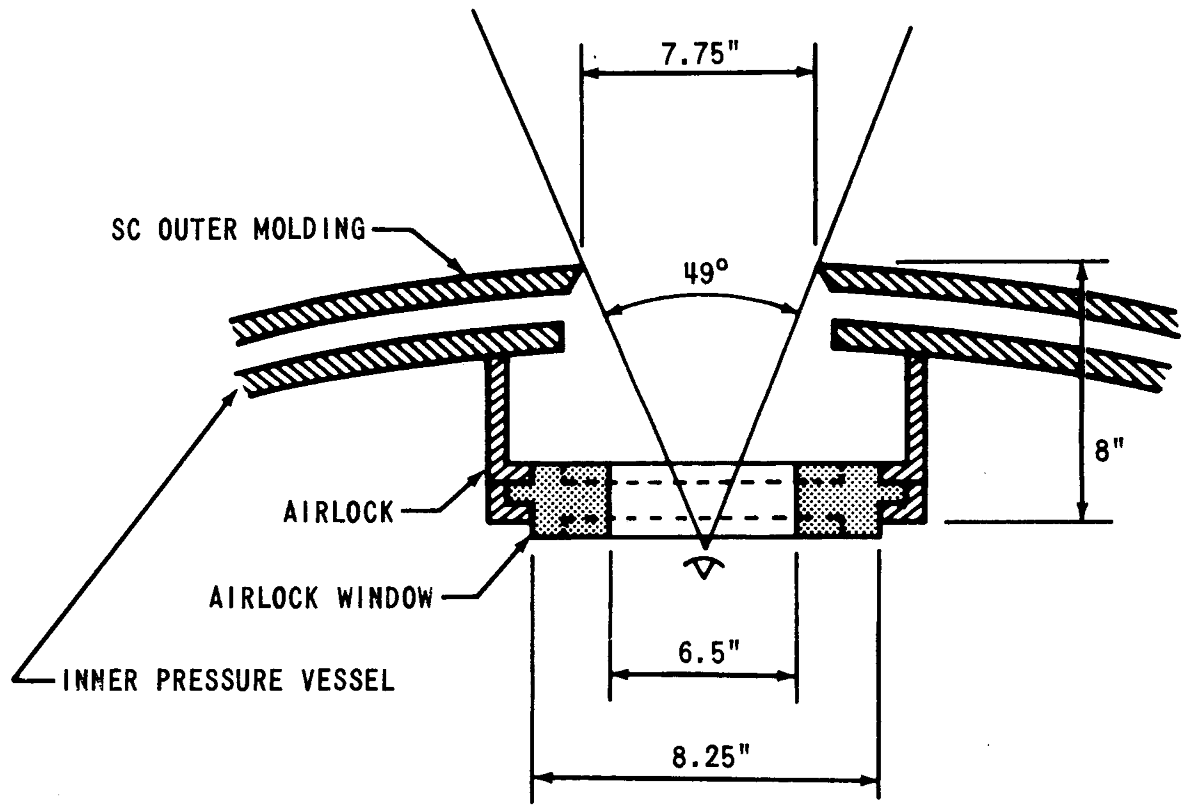

FIGURE 6 - VISUAL ACUITY ANGLE FOR AIRLOCK WINDOW (REF. 7)

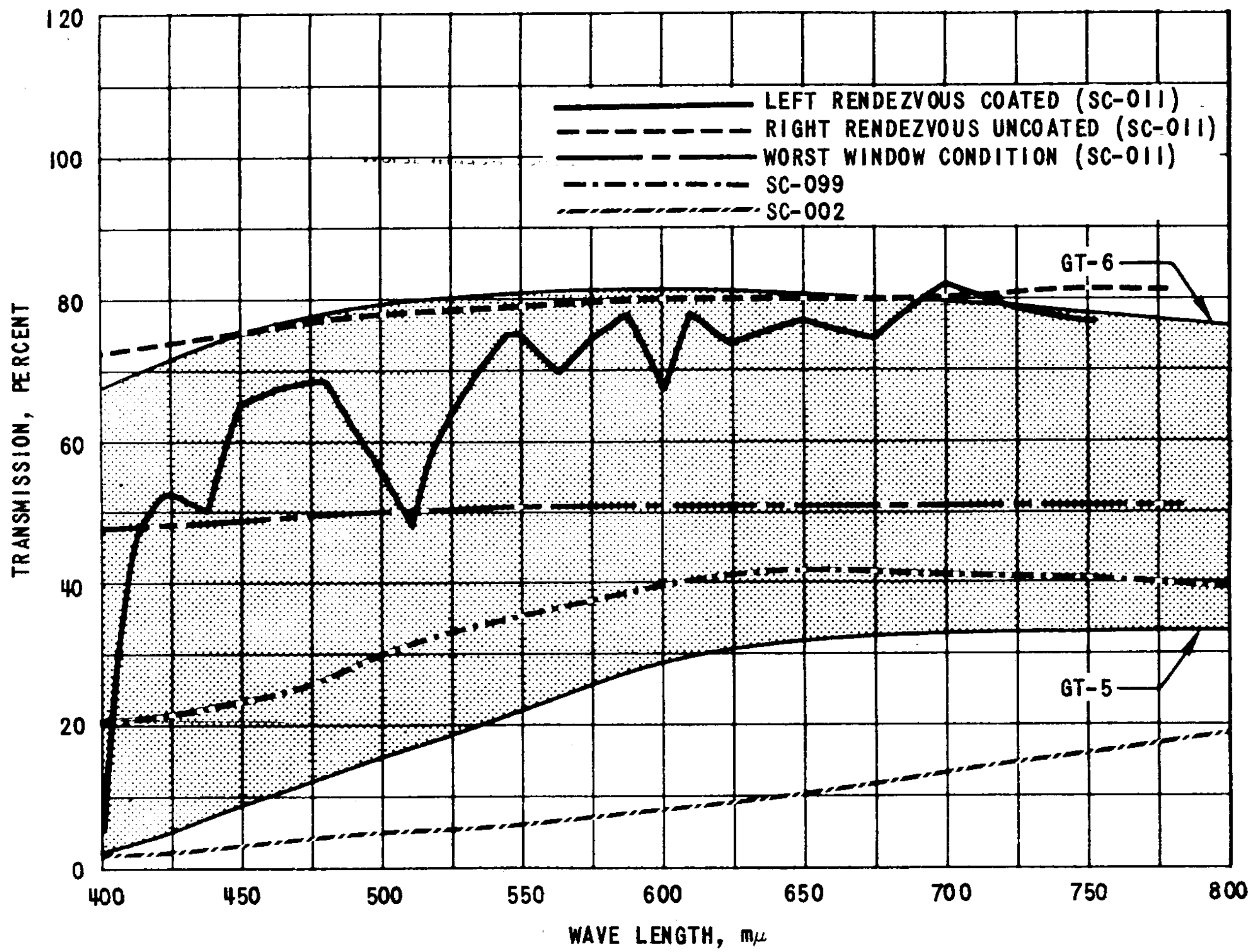

FIGURE 7 - POSTFLIGHT WINDOW SPECTRAL TRANSMISSION CHARACTERISTICS OF THREE APOLLO FLIGHTS(REF. 6)

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Subject: Feasibility of a Lunar Orbital Multispectral Photography Experiment from the CSM - Case 340

From: W. L. Piotrowski

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